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Modelling Crouch Technique to Lift Low-Lying Objects *(pp 1-12)*

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Abstract: Lifting a leading cause of lower back pain (LBP) has several industrially hygienic technique of accomplishment. One of the named crouch technique has been modelled in this study and fitted into empirical data of Nigeria female adult working population. The study was motivated by the need to provide a guiding principle for industrial engineers involved in designing jobs that are ergonomically friendly, especially at workplaces in Sub-Sahara African countries where repetitive manual lifting is still prevalently practised, and thereby constitute health hazard. We found out that adopting acute postural angle (less than 30^0) while undertaking crouch-lifting poses a serious risk factor that may cause severe lower back disorder and that the magnitude of the muscle loading within the power zone and the attendant stresses at the hip are of the order of 30 of the body weight of the subject. It is therefore cautioned that bending the trunk considerably while undertaking crouch-lifting is an unsafe act.

Key words: power zone, muscle loading, postural angle, musculature

1 INTRODUCTION

Prevention of work-related low back disorders stemming from adoption of inappropriate posture while lifting continues to be a critical component of work place health and safety programmes. Manual lifting of loads expose workers to physical conditions (for example, force, awkward postures and repetitive motions) that can lead to injuries, wasted energy, and wasted time. To avoid these problems, it is advised that organisations should strive to improve the fit between the demands of work tasks and the capabilities of workers. It is well known that workers' ability to perform work tasks may vary because of differences in height, weight, musculature and other physical conditions, as well as, age, strength, gender, stature and other factors.

Literature consulted in this study show evidence that the impact of many physical worker and workplace characteristics on lumbar spine loading during lifting have been well-documented based on fundamental principles of biomechanics. However, with advances in the development and applications of biomechanical modeling approaches, it has been demonstrated that the magnitude of lumbar spine loading (thora-columbar force) in lifting is also influenced by movements or postures adopted and the levels and patterns in which trunk muscles are activated to produce or control such movements (Beach et al, 2006) The proposed study examined the forces within the power zone, by which we mean the region of the human body between shoulder and the popliteal zone. Furthermore, the suggested approach considers two major forces within the power zone (thora-columbar force and hip abductor muscle force), simulated values for the anthropometric variables, and then fitted the model developed to a real anthropometric data of population in percentiles obtained in a preliminary survey.

This rigorous approach marks a departure from the traditional analytical technique for determining fit between physical demand of lifting and the resulting trunk and thigh muscle loadings. Back injuries from inadequate lifting methods present serious industrial risks that have been widely reported in the literature of ergonomics. Comparison between straddle lifting techniques and a 1-leg knelling lifting technique, on the one hand, with stoop lifting and squat lifting techniques, on the other, with respect to their effects on low back loading was carried out. Twelve men with no history of low back pain participated in the study. The subjects lifted wide and narrow 20 kg boxes from two initial hand heights and measured kinematics, ground reaction forces and electromyography, and then calculated the attendant three dimensional spinal forces. It was concluded that no single lifting technique can be advised for all lifting conditions (Kingman et al, 2006). An assessment of 1063 lifting and lowering tasks was carried out and the associated individual task parameters analysed. The survey was conducted as part of an epidemiological study of the relationship between low-back workers' compensation claims and the physical demands of lifting and lowering tasks. The author obtained a summary statistics of the parameter values of a large sample of actual lifting and lowering tasks and claimed that the statistics showed fairly strong agreement with some previous surveys, mutatis mutadis (Demsey, 2003). A model based on spine kinematics and bilateral lumbar and thoracic erector spinae electromyogram signals was developed with the data from eight male subjects which could be applied for the continuous estimation of erector spine (Potvin,1996). Physiological and psychophysical research approaches were employed to, among other things, compare bag lifting and box lifting. It was found out that the maximum acceptable weight of lift for bag lifting tasks was higher by 2.21 kg than for box lifting tasks under the conditions of the experiment (Smith and Jiang, 1984). A new methodology for generating the optimum motion patterns for para-sagittal lifting tasks was proposed and a computer program that predicts lifting motion patterns developed. The results compared actual versus predicted lifting patterns (Chang, 2001). Bending and compressive stresses acting on the lumbar spine during lifting activities were examined and it was noted that complex spinal loading during lifting tasks depends as much on the speed of movement, and the size and position of the object lifted, as well as its mass (Dolan et al, 1994).

Several scholars have been curious about the effects of lifting task in work places and the dangers posed by such task to workers. The establishment of a relationship between lifting capacity and anthropometric variables was carried out (Grossand Battie, 2002). In 1994, the International Labour Organization (ILO) conducted a study on maximum permissible weight to be lifted by a worker (ILO, 1994). Muscoskeletal disorders resulting from task associated with lifting was studied by Hakkanen et al (Hakkanen et al, 1997). Standardized pre-employment strength positions for lifting (arm leg, torso) were evaluated by Keyserling et al (1986). Zhang et al (2002) found a maximum lifting frequency for various tasks. More recently, National Institute for Occupational Safety and Health (NIOSH, 2009) stipulated standard for carrying out lifting tasks.

In that regard, the literature consulted in this study, with the exception of Potvin et al (1994) presented limited kinetic modelling of lifting operation. The current study adopts sophisticated approach to develop models for predicting trunk muscle and force abductor muscle loadings and their effect on the spine and hip members for subjects undertaking crouch lifting. Spectacularly, our results show that lifting activity is more physically demanding and particularly more hazardous, in terms of industrial hygiene, than bending over tasks. The average person concept assumed in the course of this research may result to generalization that may create discrepancies between actual and predicted values.

2 METHODOLOGY

This study is an analytical and applied research. An anatomical model of a subject lifting an object is sketched, see Figure 1. The associated free body diagrams are drawn and shown in Figure 2 and Figure 3.

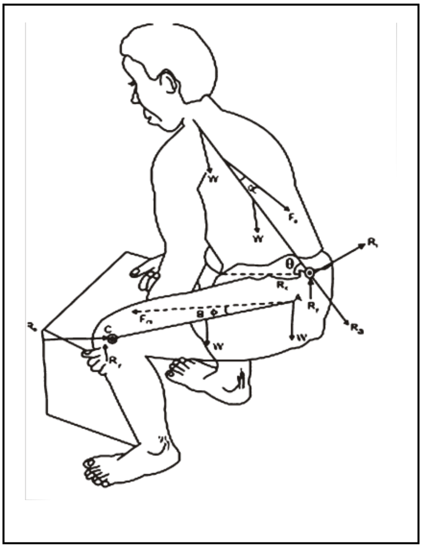


Figure 1: An Anatomical Model of a Person Performing Crouch Lifting

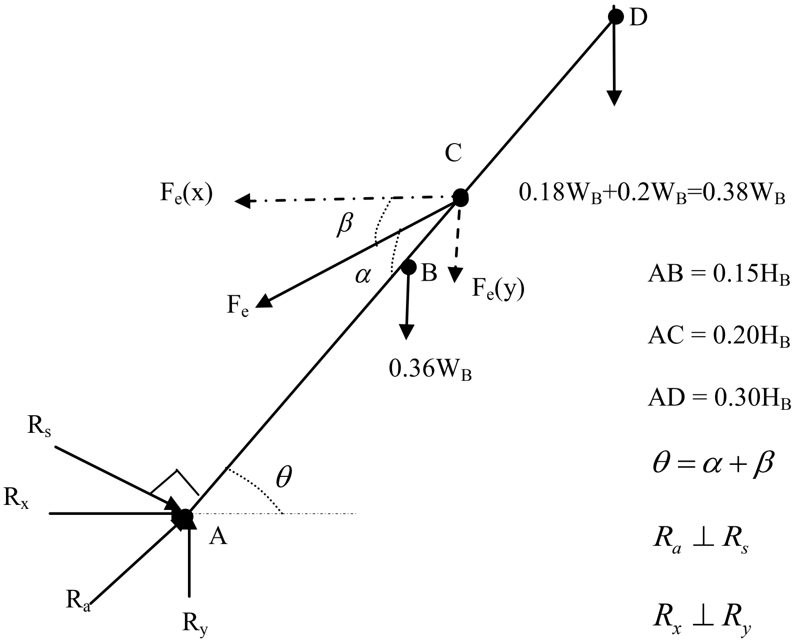


Figure 2: Free Body Diagram of the Upper Section of the Power Zone

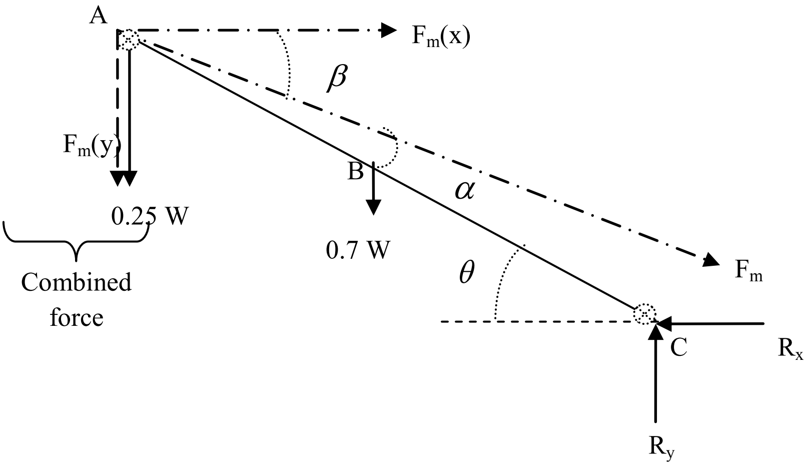


Figure 3: Free Body Diagram of the Lower Section of the Power Zone

Appropriate model parameters were assigned and model assumptions necessary for making the formulation mathematically tractable were made. The theory of force resolution and application of moments were drawn from the field of Biomechanics. The model developed was fitted into anthropometric data obtained from field measurements of some Nigerian female working population. Numerical results were obtained in the form of tables and figs. Finally, the results were discussed and our opinion, based on the findings, was expressed.

Two basic body parameters namely: height at erect position (H) in metres and body weight (W) in Newton were considered. The various body parts dimension and weight were assumed to be respectively proportional to the height and weight of the subject. The constants of proportionality are depicted in Table1.

Table 1: Anthropometric Modelling Data

Body Segment	Segment Length (Fraction of height, H)	Segment Weight (Fraction of weight, W)
Head and neck	0.17	0.08
Forearm and hand	0.20	0.20
Upper arm	0.20	0.03
Arm	0.40	0.05
Head, neck and both arms	-	0.18
Thorax and abdomen	0.30	0.36
Pelvis	-	0.16
Foot and foreleg	0.29	0.05
Upper leg	0.24	0.10
Leg	0.53	0.15
Head, neck, both arms, thorax, abdomen, and three-eights pelvis	-	0.60
One leg and five-eighths pelvis	-	0.25

Source: (Lenzi et al, 2003)

The anthropometric survey, depicted in Tables 2 and 3 establish the following relationships. Midpoint of spine measured from pelvic girdle (AB) equals half the ratio of “shoulder to buttock” distance to that of “standing height” which is 0.15H. The distance of the point of attachment of erector muscle tensor to the spine from the pelvic girdle (AC) equals the ratio of “below shoulder to buttock” distance to that of standing height which is 0.20H; while the distance from the end point of the thora-columbar spine to the pelvic girdle (AD) equals the ratio of “shoulder to buttock” distance to that of standing height which is 0.30H.

Table 2: Anthropometric Data of Male and Female Undergraduate Students of University of Benin, Benin City, Nigeria.

Percentile	**Weight (kg)**		**Height (m)**		**Shoulder To Buttock (m)**		**Below Shoulder to Buttock (m)**	
	Male	Female	Male	Female	Male	Female	Male	Female
5th	55	52	1.62	1.55	0.49	0.50	0.33	0.33
25th	62	59	1.70	1.59	0.53	0.52	0.35	0.34
50th	68	62	1.75	1.64	0.55	0.54	0.36	0.36
75th	74	69	1.80	1.69	0.58	0.56	0.32	0.37
95th	86	81	1.90	1.75	0.63	0.60	0.42	0.40

Table 3: Anthropometric Data of Nigeria Male and Female Adult Working Class

Percentile	**Weight (kg)**		**Height (m)**		**Shoulder To Buttock (m)**		**Below Shoulder to Buttock (m)**	
	Male	Female	Male	Female	Male	Female	Male	Female
5th	47.00	45.00	1.49	1.51	0.47	0.29	0.31	0.29
50th	64.00	58.00	1.72	1.63	0.56	0.35	0.37	0.35
95th	85.40	92.60	1.88	1.83	0.66	0.41	0.44	0.41

Systems Model. Reference to Figure 1, Figure 2 and Figure 3,

Case (i):

It is assumed that the weight of the load being lifted, W_L is $0.2W_B$.

$\alpha+\beta=\theta$, as assigned in the FBD

$F_e(x)=F_e\cos\beta$

$F_e(y)=F_e\sin\beta$

F_m = force abductor muscle force at the lap

We recall that $\sum F_y=0;\uparrow^{+}$

$$R_y=0.74W_B+F_e\sin\beta \qquad (1)$$

$\sum F_x=0$

$$R_x = F_e \cos\beta \qquad (2)$$

Furthermore $\sum M_A \curvearrowleft^{+} = 0$

$$-F_e(x).AC\sin\theta + F_e(y).AC\cos\theta + (0.36W_B)AB\cos\theta$$
$$+(0.38\mathrm{W_B}).AD\cos\theta = 0$$

Substituting for $F_e(x)$, $F_e(y)$, AC, AB and AD:

$$\Rightarrow -F_e\cos\beta.(0.2H)\sin\theta + F_e\sin\beta.(0.2H)\cos\theta + (0.36W)(0.15H)\cos\theta$$
$$+0.38\mathrm{W}.(0.3H)\cos\theta = 0$$

Notice that H cancels out because it is common to all terms

$$\therefore F_e = \frac{0.84W\cos\theta}{\sin(\theta-\beta)} = \frac{0.84W\cos\theta}{\sin\alpha} \qquad (3)$$

Case (ii)

Let $F_1 = 0.25\mathrm{W}$

$F_2 = 0.7\mathrm{W}$

$\beta + \alpha = \theta$

Take moment about C:

$$-\left[F_m\sin\beta + F_1\right]AC\cos\theta - F_2BC\cos\theta + F_m\cos\beta.AC\sin\theta = 0$$

Collecting like terms and observing that AC, which is common to both sides of the equation, cancels out.

$$F_m(\cos\beta\sin\theta - \sin\beta\cos\theta) - (F_1\cos\theta + \tfrac{1}{2}F_2\cos\theta) = 0$$

Therefore,

$$F_m = \frac{(F_1\cos\theta + \frac{1}{2}F_2\cos\theta)}{(\cos\beta\sin\theta - \sin\beta\cos\theta)}$$

From trigonometric identities, $\sin(\theta-\alpha) = \sin\theta\cos\alpha - \cos\theta\sin\alpha$

Hence,

$$F_m = \frac{\left(F_1 + \frac{1}{2}F_2\right)\cos\theta}{\sin(\theta-\beta)}$$

Since $\alpha = \theta - \beta$

$$F_m = \frac{\left(F_1 + \frac{1}{2}F_2\right)\cos\theta}{\sin\alpha}$$

$$F_m = \frac{0.6W\cos\theta}{\sin\alpha} \tag{4}$$

The vector diagrams for the computation of axial reaction and shear reaction forces are shown in Figure 4 and Figure 5.

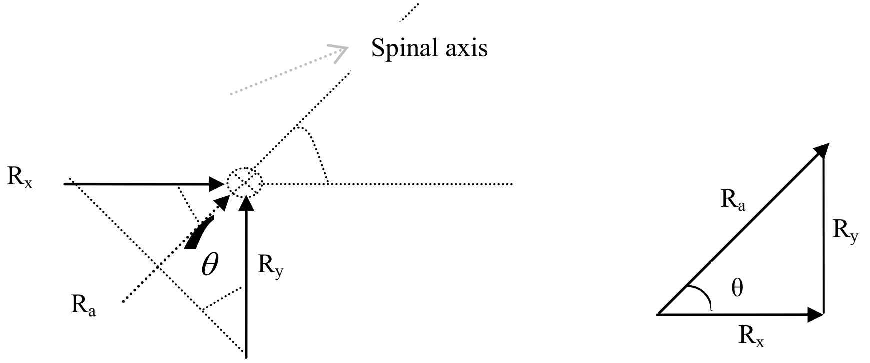
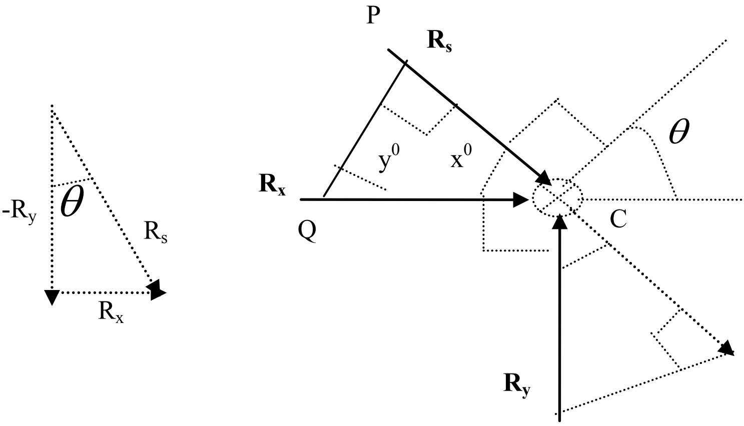


Figure 4: Vector Diagrams for the Computation of Axial Reaction Force along the Central Axis of Spine



$x^0 + 90 + \theta = 180^0$

$x^0 = 90 - \theta$

And for ΔPQC :

$y^0 + x^0 + 90 = 180^0$

$\Rightarrow y^0 = 90 - x^0$

Figure 5: Vector Diagrams Trigonometric Expression for the Computation of Shear Reaction Stress Perpendicular to the Axis of Spine

It is evident from Figure 4 and Figure 5 that the axial reaction force (R_a) and shear reaction force (R_s) are as follow:

$$R_a = R_x \sec\theta = R_y \cos ec\theta \tag{5}$$

$$R_s = R_x co\sec\theta = -R_y \sec\theta,\ \mathrm{R_a} \perp \mathrm{R_s} \tag{6}$$

3 COMPUTATIONS AND NUMERICAL RESULTS

Table 4 summarizes the loadings and stresses as well as trigonometric values of the anthropometric variables associated with the Nigerian female working class in percentiles. As α varied from 1 to 20 degrees, β from 5 to 100 degrees, θ from 6 to 120 degrees, for the corresponding body weights of 450 N (5th percentile), 580 N (50th percentile) and 926 N (95th percentile), the loadings and stresses decreased monotonically.

Table 4: Computation of the Erector Muscle Force, F_e, Hip Abductor Muscle Force, F_m, Axial Reaction Force, R_a, and Shear Reaction Force, R_s for Nigeria Female Working Class

Percentile	Weight (N)	Anthropometric Variables			Computed Data						
		α	β	Θ	F_e (N)	F_e/W	R_x (N)	R_y (N)	R_a (N)	R_s (N)	F_m (N)
5	450	1	5	6	13498.65	30	13447.36	485.98	13446.01	1405.25	14998.50
		5	25	30	2418.83	5	2192.18	210.44	1898.43	1096.09	2687.59
		10	50	60	698.28	2	448.85	121.50	224.43	388.71	775.86
		15	75	90	0.00	0	0.00	0.00	0.00	0.00	0.00
		20	100	120	-355.26	-1	61.71	-121.50	-30.85	53.44	-394.74
50	580	1	5	6	17398.26	30	17332.15	626.37	17330.41	1811.21	19331.40
		5	25	30	3117.60	5	2825.48	271.23	2446.87	1412.74	3464.00
		10	50	60	900.00	2	578.52	156.60	289.26	501.00	1000.00
		15	75	90	0.00	0	0.00	0.00	0.00	0.00	0.00
		20	100	120	-457.89	-1	79.54	-156.60	-39.77	68.88	-508.77
95	926	1	5	6	27777.22	30	27671.67	1000.03	27668.90	2891.69	30863.58
		5	25	30	4977.41	5	4511.03	433.03	3906.55	2255.51	5530.46
		10	50	60	1436.90	2	923.64	250.02	461.82	799.87	1596.55
		15	75	90	0.00	0	0.00	0.00	0.00	0.00	0.00
		20	100	120	-731.05	-1	126.98	-250.02	-63.49	109.97	-812.28

The import is that stresses arising from body muscle exertion while stooping and lifting increase with acuteness of the postural angle, θ. Correspondingly, since θ is a linear function of α and β ($\alpha + \beta = \theta$), therefore, force erector muscle and force abductor muscle located at the trunk and thigh respectively increase in magnitude.

It is evident from the force erector muscle/weight ratio column that at extreme postural angle, the loading on the trunk muscle and thigh muscle are about 30 times the body weight of the subject and this is capable of causing disorders at the lower back.

Figure 6 and Figure 7 depict how the erector muscle force and hip abductor muscle force vary with postural angle for the 5th, 50th and 95th Nigerian female working class respectively.

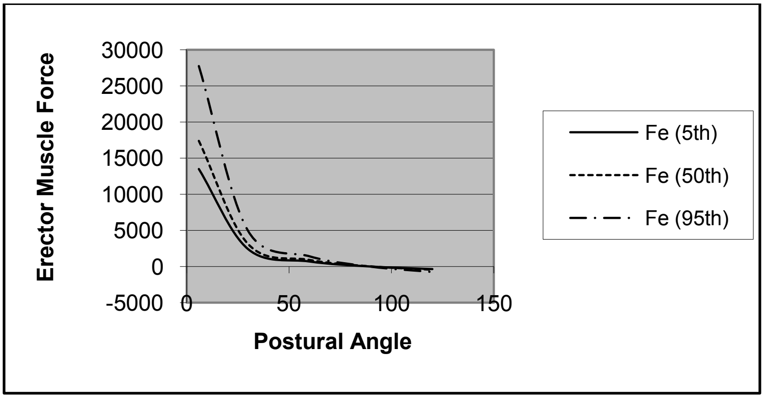


Figure 6: Erector Muscle Force and the Postural Angle Plot

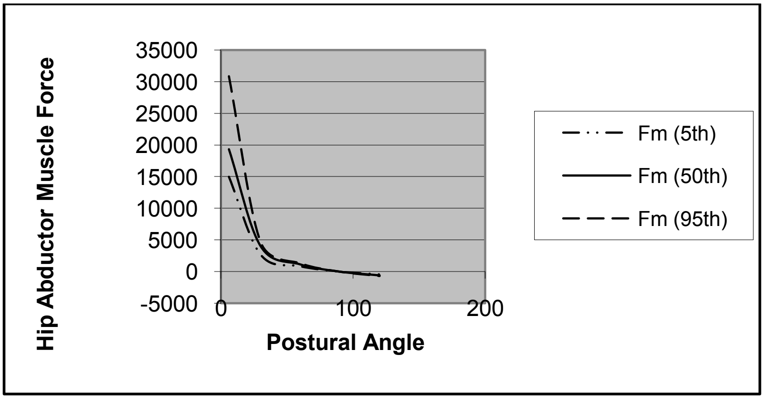


Figure 7: Hip Abductor Muscle Force and the Postural Angle Plot

It is evident from the Figures that 30^0 postural angle appears to be the threshold from which muscle forces under study begin to assume critical values. It corresponds to the elbow of the force characteristics. Then, below this threshold value, that is postural angle less than 30^0, the loadings in the muscle and the associated stresses in the lower back tend to assume values that can cause profound disorder (noxious). For example in Figure. 6, for the 5th percentile population, at acute postural angle, erector muscle force of 15 kN can be generated, as against 30 kN for the 95th percentile. Previous studies have reported forces in the order of mega Newton (Eckstein et al, 1999).

4 DISCUSSION OF RESULTS

The results obtained in this study will constitute empirical evidence that can guide industrial engineers in designing lifting jobs that can fit workers bearing in mind their physical and psychophysical demands. The muscle exertions as well as stresses at the hip that are responsible for lower back pain have been quantified in terms of body weight order. Interestingly, when subjects lift at postural angle of 120^0, a negative force would be generated across the hip, whereas about twice the magnitude of such force (orthogonal), this time around positive, will be generated along the spine. It is therefore not advised that lifting should be done at reflex postural angles (awkward posture) to avoid suddenly buckling under.

Reference to the research problem, it is the view of the authors that the results of this study can be particularly needful for designing appropriate loads that can be carried by individuals in Nigerian industries and Sub-Sahara African countries in general. In the mean time, the decision on the amount of load to be carried is determined by gumption which is rather subjective. For example, in a particular firm where rubber latex is produced in large quantities, men and women are required to lift 45 kg by sagittal operation. And there have been complaints of back disorders which often lead to loss of man hour and hence reduce productivity. This observation has been collaborated by literature report (ILO, 2000).

5 CONCLUSION

Arising from our findings, the following conclusions can be noted.
In crouch lifting, postural angles below 30^0 can generate forces and stresses capable of causing lower back disorder.
At extreme postural angles (less than 30^0), the loading on the back and thigh muscles are about 30 times the body weight of the subjects
Overall, crouch lifting involves stooping and squatting while lifting and the effect is a compressive stress on the spine and hip and bending moment on the trunk.
It is therefore advised that subjects should avoid lifting from the floor whenever possible. And if one must lift from the floor, they need not bend at the waist.

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